Benefits in Cost and Reduced Discomfort of New Techniques of Minimally Invasive Cavity Treatment

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The concept of minimally invasive dentistry is appealing to more and more dentists. Patients share this enthusiasm. Three basic principles underlie minimally invasive dentistry: prevention of dental caries, less intrusive treatment for early lesions, and conservation of tissue when deeper lesions are restored. Together, these principles improve patient well-being by prolonging the life of teeth and by reducing the need for uncomfortable and costly dental treatments.

Several minimally invasive techniques are already part of normal clinical practice. Caries prevention is now routinely improved by exposure of dental enamel to fluoride, the sealing of pits and fissures, and teaching of adequate oral hygiene (NHS, 1999; FDI policy statement, 2002). Current treatment of early enamel lesions combines topical application of fluoride to promote remineralization, encouraging habits of oral hygiene, the use of chlorhexidine to reduce the number of cariogenic bacteria, and the use of enamel pastes to rebuild enamel (FDI policy statement, 2002).

The conservation of tissue during the restoration of caries lesions, the third aspect of minimally invasive dentistry, has proven to be more challenging. We shall describe tools and materials now available to treat deeper caries lesions, and highlight areas where further development and testing is needed. Inevitably, there are obstacles that we identify. But, thanks to several research groups, the problems are disappearing. It seems entirely practical to overcome remaining difficulties. We hope we can motivate efforts to address the remaining hurdles, so all can benefit from the reduced cost and discomfort of minimally invasive techniques.

Tissue conservation during restoration, as currently perceived, makes use of adhesive filling materials, rather than amalgam. Infected and undermined tooth tissue must be removed, whether for amalgam or for adhesive filling. Adhesive fillings conserve more tissue than amalgam: After the surface has been etched, the filling adheres strongly to it for any reasonable cavity shape. In contrast, amalgam does not adhere to the cavity surface: The cavity must be shaped so the amalgam stays in place, removing further healthy material even after the infected tissue has gone.

How durable are current restorations? Sadly, only 80% of current amalgam restorations are still in good condition after 10 years. The survival rates of restorations prepared with adhesive filling materials are even lower (NHS, 2001). A large restoration not only weakens the tooth mechanically, but also increases the probability of re-infection by cariogenic bacteria (NHS, 1999). Bacteria ultimately regain access to treated sites wherever the filling material adheres poorly to the tooth. A rate of 80% means that most restorations will need replacement, possibly more than once in a lifetime. Whenever this happens, still more healthy dental tissue is removed, further reducing the expected life of the tooth. Short-lived restorations are costly in terms of discomfort, inconvenience, and expense. Data from the National Health Service of England and Wales show that, in 1999, replacing existing restorations accounted for over 60% of all restorative dentistry, costing a stunning £100 million. Replacing teeth with crowns, necessary when they become mechanically unstable, cost another £156 million (NHS, 1999). If minimally invasive dentistry leads to even a modest increase in the 10-year survival rate, from 80% to 90%, the number of replacement restorations needed over a period of 30 years would be reduced by 50%.

Dentists accept the importance of conserving healthy dental tissue when treating larger caries lesions. But the available techniques, tools, and materials limit ways to minimize tissue removal. Practitioners must remove significant healthy enamel and dentin overlying the carious site to remove all infected enamel and dentin, and to prepare to apply a filling. Identifying good and bad regions by eye has its limitations, and hand-held dental drills have a drilling precision of 1-2 mm at best. Could one do better?

New techniques are needed to overcome such limitations. In the mid-1990s, Pearson, Patel, Moss, Cox, Arthur, and Lawes proposed that one could access the carious site through the smallest opening possible, a tunnel less than 0.5 mm in diameter drilled with a laser or a dental bur. A bactericidal substance could then inactivate the bacteria, and the tunnel could be sealed. These steps could stop the progression of caries, and would create a much stronger and more durable restoration than conventional treatments (Fig.). While these ideas were considered interesting, they were not adopted by the dental community. Largely, this was because the necessary technology was not available, and what was available was not well-suited to the new needs.

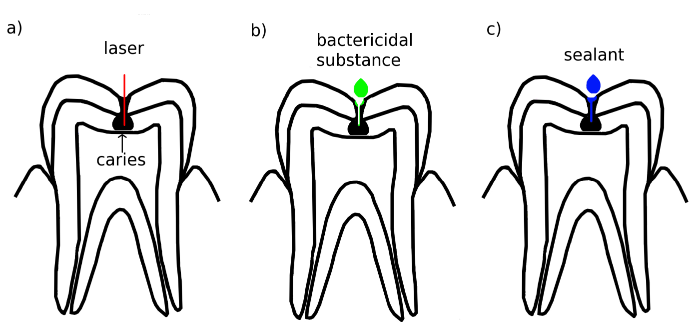

Figure 1: Schematic of a proposed minimally invasive technique for treating cavitated carious lesions. After locating the carious region, the first stage (a) is to create a tunnel. While dental burs of diameter 0.5 mm already exist, lasers offer the advantage of even narrower tunnels. Subsequently (b) a bactericidal substance is used to kill the bacterial and (c) the tunnel is sealed off.

The first step in any minimally invasive approach is to establish the precise location and extent of caries in the tooth, so that one can decide the best location for the tunnel. Larger caries lesions are easier to detect, so standard x-ray imaging plus visual inspection may suffice to decide the optimum place and orientation for the tunnel. Smaller lesions needing surgical treatment are more challenging, but there are promising new methods. These exploit changes in the fluorescence of the tooth in either the visible or infrared wavelength regions of the light spectrum.

One of the available methods locates caries at least as well as visual inspection. Its high sensitivity implies few false-positives (identifying a healthy site as actually carious), and its high specificity means that the system will produce few false-negatives (identifying a carious site as actually healthy). While it does not do better than humans at detecting caries, the method has two advantages over visual inspection. First, it can image the carious site to a computer screen, allowing for very detailed observation. Second, it estimates the area and depth of the carious sites, except interproximal ones. The method thus provides all necessary information the clinician needs to decide where to make the tunnel. Interproximal caries is especially challenging to detect, due to the difficulty in accessing the site. It may be detected with a different system, one that uses a narrow and long tip to deliver and detect electromagnetic radiation. Commercially available systems for detecting interproximal caries have shown good sensitivity and specificity. Unfortunately, they do not provide an image of the caries lesion, nor do they quantify its area and depth. When treating interproximal lesions, the practitioner must also use other methods, like x-ray images, to select the optimum tunnel position when restoration is necessary. There is clear scope for research to enhance sensitivity and specificity of these systems and, for interproximal lesions, to find ways to identify precise locations, surface areas, and depths.

If you know the existence and extent of the caries, and if you have decided on surgical treatment, what tools are available to drill the tunnel? It will be narrow (diameter < 0.5 mm) and may pass through overlying healthy enamel, dentin, and filling material. Dentists already use drills, though the available standard dental drills of 0.5-mm diameter may need further tests to see whether they are practical in a surgery to drill narrow and long tunnels without unwanted cracking of the tunnel walls. Lasers are another option, with the added advantage that even narrower tunnels may be possible. Of the several laser systems tested for dental hard tissue ablation (reviewed by Vila Verde et al., 2007), the CO_2 laser stands out. This laser (operating at a wavelength of 10.6 micrometers) can remove dental hard tissue reproducibly and without unwanted side-effects, provided that pulse durations are around 10 microseconds (Fried et al., 2001; Vila Verde et al., 2007). Earlier laser systems used much longer pulses, giving CO_2 lasers a reputation for excessively heating the tooth. With 10-microsecond pulses, possibly combined with air or water cooling, such heating should not be an issue. This CO_2 system is inexpensive and thus very promising. It can also be used for soft-tissue dental procedures, making it more costeffective. But there is a pressing need for further studies to see how well this CO_2 laser performs when drilling narrow tunnels in different types of teeth, and even at different locations within a tooth. Tooth composition and microstructure vary significantly, both from place to place within a tooth, and also from tooth to tooth, and such variations affect both the local mechanical properties and responses to laser radiation. Further work is needed to determine how well the CO_2 laser ablates dental fillings. Should studies verify that the CO_2 laser can drill narrow tunnels through teeth reliably and reproducibly, it could rapidly move from research concept to clinical practice.

Achieving high-precision drilling needs more than access to a suitable laser or dental drill. One needs the technology to hold the laser or drill in place in the mouth, and to guide its position and orientation. Hand-held devices will not be good enough. What is needed is a device that fixes the laser or drill to the tooth, both to aid guidance and to compensate for any movements by the patient. This device should link to a computer interface that gives both the familiar visual information via a standard camera and the information from a caries diagnosis system, such as those described above. The dental practitioner can then control the laser or drill precisely as it creates the tunnel, just as medical surgeons carry out minimally invasive surgery. Such a system is essential if minimally invasive techniques are to be used in clinical practice. While they do not exist at present, their development from existing surgical models would seem to be relatively straightforward.

High precision in drilling means knowing when to stop. How can we know when the carious site has been reached? Three ideas have been suggested. The first is mechanical, using a computer analysis of the sound produced during laser ablation: The laser ablation of enamel, dentin, and carious tissue gives characteristic sound 'signatures'. The second would use 'on-the-fly' mass-spectrometry analysis and could be used with both laser and dental bur drilling. While more complicated, there would be the added benefit of giving the practitioner a detailed chemical analysis of the ablated material, and better characterization of the caries lesion. A third possibility would be to detect fluorescence of the removed material. This could be done with slight modifications to the caries detection systems described above, and could also be used with both lasers and dental burs. Further work is needed to validate detection systems based on sound analysis and assess their reliability. Likewise, small, reliable, and inexpensive mass spectrometers need to be developed in a form that can be used in a clinical setting. All three methods would benefit from practitioner know-how and experience to understand how best to characterize carious sites and improve patient well-being.

Once the tunnel has been made, the bacteria in the carious site must be destroyed. Studies confirm that photo-activated bactericidal agents can effectively kill bacteria in root canals and dentin. Such agents include toluidine Blue O and aluminum disulphonated phthalocyanine (Burns et al., 1994; Williams et al., 2004). Once a small amount of the bactericidal agent is in the cavity, it diffuses quickly in the carious tissue, reaching bacteria buried more deeply. Irradiation with a laser for a few seconds activates the agent, which destroys bacteria. Typical wavelengths are 633 nm for toluidine Blue O and 830 nm for aluminum disulphonated phthalocyanine, and can be provided by small, inexpensive diode lasers. Such wavelengths are poorly absorbed by dental tissue, giving two advantages. First, the lasers are safe for use in vivo. Second, the light can pass relatively easily through healthy enamel and dentin to reach the carious tissue where the bactericidal agent is to be found. Probably, light will be brought from the laser source via fiber optics, with the tip of the fiber inside the cavity or just above it. This allows for enough light to enter for a usefully high fraction of bacteria (above 90%) to be destroyed (Burns et al., 1994; Williams et al., 2004).

Sealing the tunnel completes the restoration. Existing filling materials with low viscosity might be injected by syringe into a very narrow tunnel. Materials based on methacrylates or dimethacrylates look promising, including one based on 50% THFMA (tetrahydrofurfuryl methacrylate), 33% UDMA (urethane dimethacrylate), and 17% BisGMA (bisphenol-A-glycidyl dimethacrylate). These materials can be cured with the 450-nm light already commonly used in dental practices, or by means of initiators like benzoyl peroxide or activators such as N,Ndimethyl-p-toluidine (Wilson et al., 2000).

The message we stress is that much of the necessary technology already exists to test and even implement minimally invasive ways to treat carious teeth. Some of the techniques still needed may prove relatively simple developments from the minimally invasive surgery that is already commonplace. Most, if not all, outstanding issues need dental researchers, clinical practitioners, engineers, and scientists to work together. Ideally, the lead should come from those who want to make minimally invasive methods work. Minimally invasive approaches bring the opportunity to improve patient experience and offer a route to improved dental health and associated social gains. We hope that these ideas might rekindle the dental community's interest in minimally invasive approaches, so that such collaborations between practitioners and those from the physical sciences can develop to the advantage of all.

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References

Burns W, Pearson GJ, Wilson M (1994). Killing of cariogenic bacteria by light from a gallium aluminum arsenide diode-laser. J Dent 22:273-278.

FDI World Dental Federation (2002). FDI policy statement: minimal intervention in the management of dental caries. FDI World Dental Federation, France. Online only at http://www.fdiworldental.org/federation/assets/statements/ENGLISH/Minimal_Intervention/Minimal_intervention_caries.pdf.

Fried D, Ragadio J, Akrivou M, Featherstone J, Murray MW, Dickenson KM (2001).

Dental hard tissue modification and removal using sealed transverse excited atmospheric-pressure lasers operating at 9.6 and 10.6 micrometers. J Biomed Opt 6:231-238.

NHS (1999). Effective health care — Dental restoration: what type of filling? National Health Service Centre for Reviews and Dissemination, University of York, United Kingdom. http://www.york.ac.uk/inst/crd/EHC/ehc52.pdf

NHS (2001). The longevity of dental restorations — a systematic review. National Health Service Centre for Reviews and Dissemination, University of York, United Kingdom. http://www.york.ac.uk/inst/crd/CRD_Reports/crdreport19.pdf

Vila Verde A, Ramos MM, Stoneham AM (2007). The role of mesoscopic modelling in understanding the response of dental enamel to mid-infrared radiation. Phys Med Biol 52:2703-2717.

Williams JA, Pearson GJ, Colles MJ, Wilson M (2004). The photo-activated antibacterial action of toluidine blue O in a collagen matrix and in carious dentine. Caries Res 38:530-536.

Wilson M, Clements DJ, Pearson GJ, Williams JA, Colles MJ, Hamilton DC (2000). Method and apparatus for treating dental caries. Canadian Patent 2365342. April 14. http://patents.ic.gc.ca/cipo/cpd/en/patent/2365342/summary.html